THE CENTRAL HIGH PLAINS STORM OF NOVEMBER 1-3, 1956

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1. INTRODUCTION

The first severe snow storm of the 1956–57 season in the High Plains began on November 1, and continued through November 3, 1956.

The storm left up to 20 inches of snow in northwestern Nebraska, and driven by winds of 50 to 70 m. p. h., huge drifts were formed, paralyzing traffic and disrupting communications. Several deaths were attributed to the storm. The storm reached blizzard proportions on November 2. It met all qualifications of the "severe blizzard" except that temperatures were not low enough.

Hardest hit was the area of the Nebraska Panhandle, extreme northwestern Kansas, northeastern Colorado, eastern Wyoming, and extreme western South Dakota. The storm snowfall pattern shown in figure 1 is based on snow depths reported at 0630 CST, November 4, from stations reporting regularly by teletypewriter, plus a special report from Harrison in the northwestern corner of Nebraska. Also shown is the path and central pressure of the sea level low pressure center.

The development of the storm was rather typical of the High Plains blizzard type or Colorado Low, but the path was unusual in that the storm moved northwestward out of the Nebraska area, filling rapidly as it passed through western South Dakota.

The purpose of this paper is to review some of the synoptic aspects of the storm, and to present practical approaches to the forecasting of its development and the associated precipitation.

2. EARLY STAGES

An important prelude to both the development and the peculiar path of the storm was the persistent warm ridge centered over the eastern third of North America. The strength of this ridge was reflected in positive departures from normal of the 5-day mean 700-mb. heights of more than 600 feet near the St. Lawrence Valley. This positive anomaly had its origin over the Ohio Valley the second week in October, moved rather quickly to the St. Lawrence Valley, and intensified in that position. The strength of this ridge was also reflected in abnormally cold stratospheric air (−65° C. at 200 mb. over James Bay at 1500 GMT, October 30, fig. 2) which persisted over

northeastern United States and eastern Canada for a considerable period of time.

An upper trough began deepening in the Gulf of Alaska on the 29th, and was approaching the west coast of North America by 1500 GMT, October 30 (fig. 3).[1] As this trough moved inland, accompanied by a strong mP front, a

[1] The general evolution of the storm is shown in figures 3–6, copied from facsimile charts. Being general in nature, they may disagree in details of exact storm positions given elsewhere.
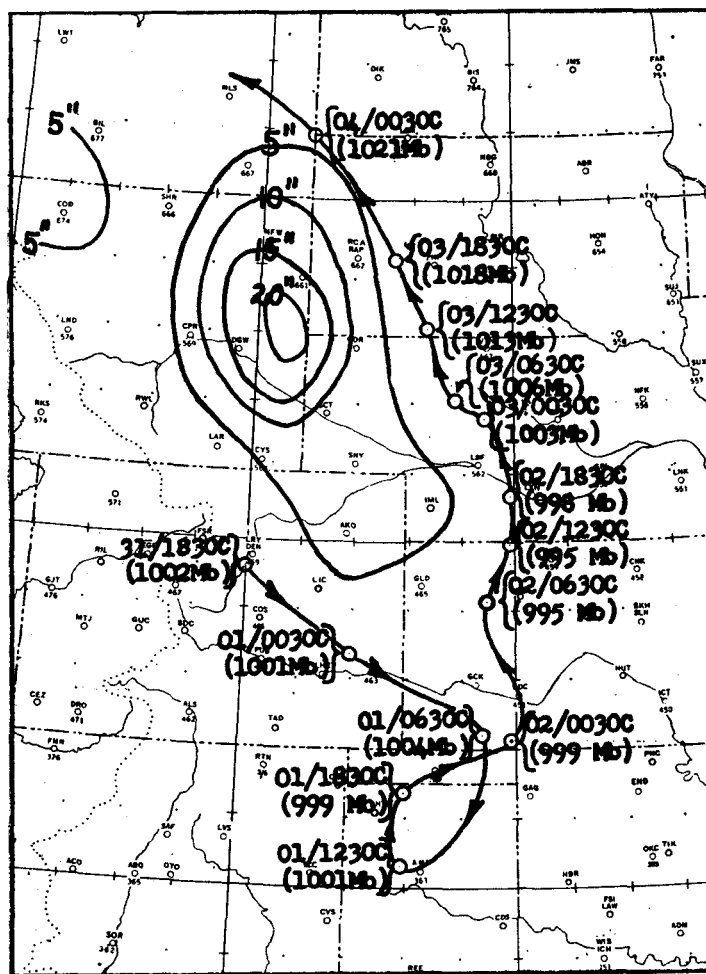

FIGURE 1.—Isopleths of storm snowfall (inches) for November 1–3, 1956, together with successive positions and central pressure of the sea level Low center.
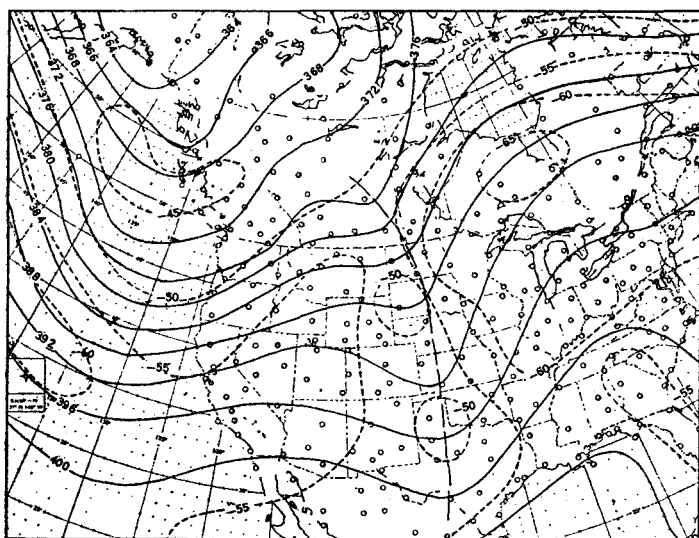
FIGURE 2.—200-mb. chart for 1500 GMT, October 30, 1956. Solid lines are contours labeled in hundreds of feet, and dashed lines are isotherms labeled in degrees Celsius.
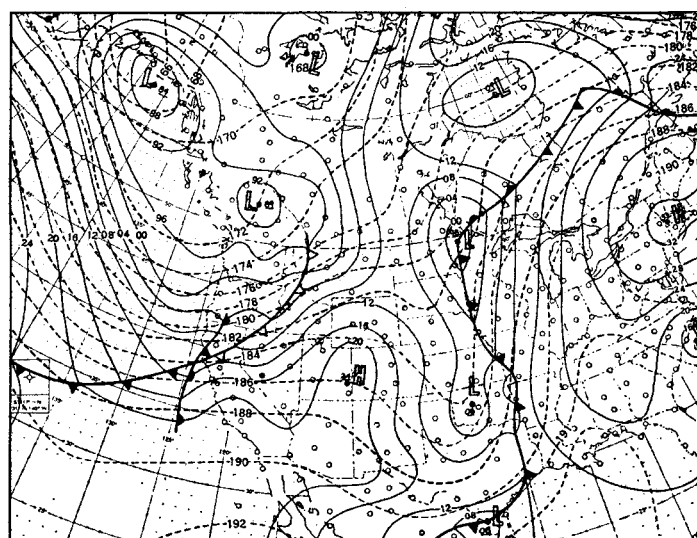

FIGURE 3.—Composite sea level chart (solid lines, 1230 GMT) and 500-mb. chart (dashed lines, 1500 GMT) for October 30, 1956. Surface fronts are indicated with standard symbols. The system near the west coast later developed and became the important storm.

FIGURE 4.—Composite sea level and 500-mb. chart for October 31, 1956.

surface Low formed on the front in the Central Plateau (fig. 4) and moved from northeastern Nevada to western South Dakota by 0030 GMT, November 1. This center subsequently filled rapidly, while a secondary Low formed in the area of central Colorado. This latter center moved southeastward reaching the panhandle area of Texas and Oklahoma (fig. 5). It then recurved sharply northward and intensified, becoming a major storm (fig. 6).

3. DEVELOPING STAGE

The development of this storm appears to fit quite well the model proposed by Petterssen. Petterssen et al. [1] hypothesize, ". . . cyclonic development at sea level occurs when and where an area of positive vorticity advection in the upper troposphere becomes super-imposed upon a frontal zone at sea level." Let us now examine the development of this storm in the light of this hypothesis.

In this discussion, the term "development" denotes increasing circulation about the sea level low center; viz: positive values of $(\delta\zeta/\delta t)_{SL}$ following the system, where ζ is the vertical component of relative vorticity, and t is time. It is assumed that the vorticity advection pattern at 500 mb.[2] is representative of that in the upper troposphere, more specifically, at the level of nondivergence. The vorticity advection is defined as $-\mathbf{V}\cdot\nabla\eta$, where $\mathbf{V}$ is the wind vector, ∇ is the two-dimensional vector gradient operator in the pressure surface, and η is the vertical component of absolute vorticity.

Prior to development, on the forenoon of November 1, the vorticity advection pattern was relatively weak, and centered near a weak surface Low in the vicinity of
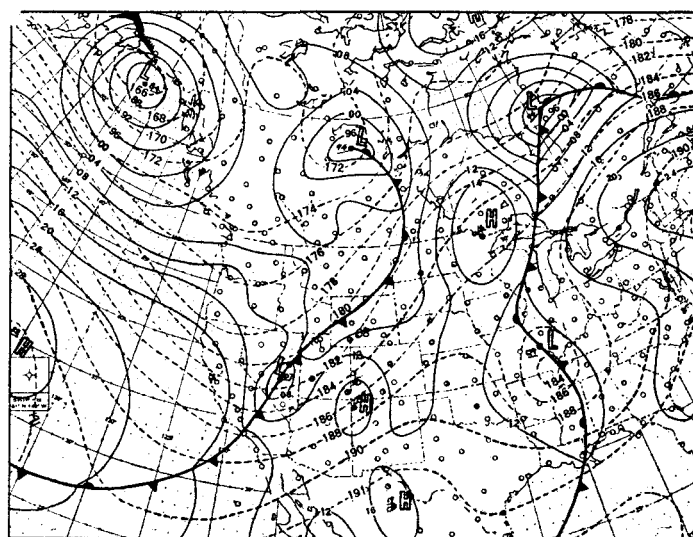
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[2] Hereafter referred to merely as "vorticity advection."

Albuquerque, N. Mex. (fig. 7). This is climatologically an unfavorable area for development. At the same time there was a weak sea level low center in the Texas Panhandle, statistically a much more favorable area for development.

By the evening of November 1 (fig. 8) a weak vorticity advection pattern still existed in the southeastern New Mexico area, but a stronger pattern had appeared in the area of western Kansas. Whether this latter pattern was associated with a trough which had moved from New Mexico during the day while a new one formed in New Mexico, or whether the trough over the Oklahoma Panhandle at 02/0300 GMT was a new development is not
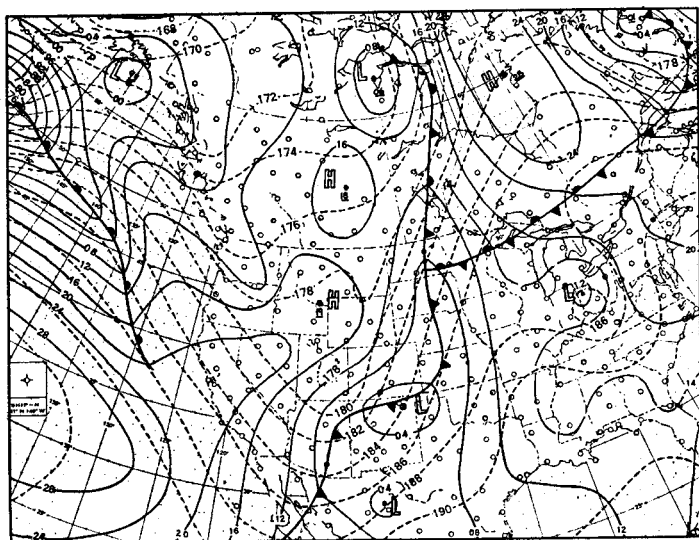
FIGURE 5.—Composite sea level and 500-mb. chart for November 1, 1956.
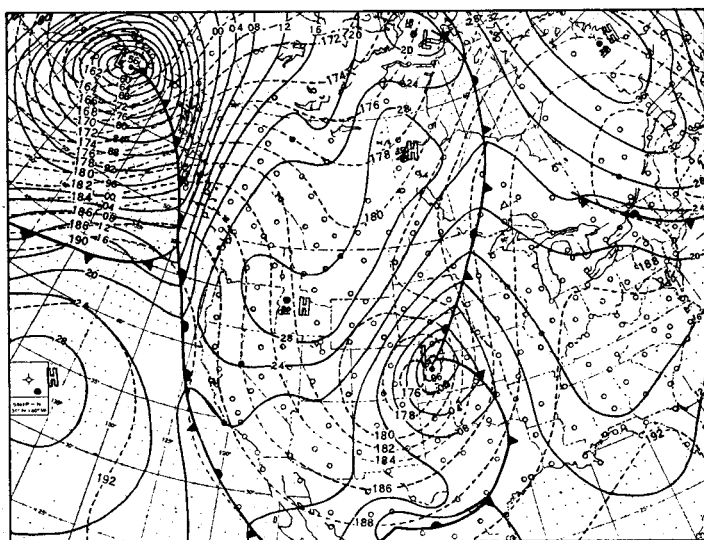
FIGURE 6.—Composite sea level and 500-mb. chart for November 2, 1956.

FIGURE 7.—500-mb. contours and vorticity for 1500 GMT, November 1, 1956. Solid lines are contours labeled in hundreds of feet, and dashed lines are geostrophic vorticity $\times 10^{-4}$ sec^{-1}. ⊕ marks the position of the sea level Low one-half hour after upper air synoptic time. Arrow connects current position of sea level Low with its position 12 hours later.
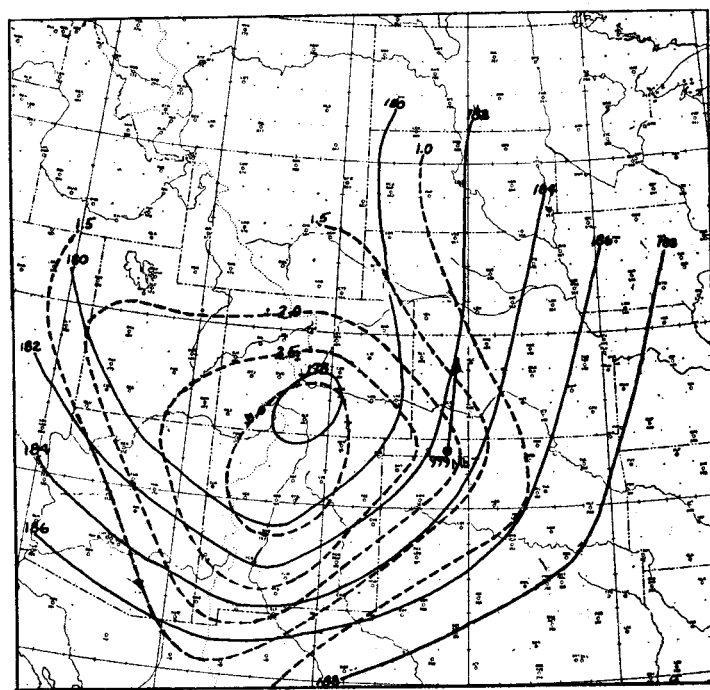
FIGURE 8.—500-mb. contours and vorticity for 0300 GMT, November 2, 1956.

known. At any rate, by that time the Panhandle Low had already begun to develop while the Low near Albuquerque disappeared. The development of the Panhandle Low was probably at least partly a result of the development of this vorticity advection pattern. This pattern subsequently retained its identity, strengthened, and moved northward and northwestward.

Figures 7–10 suggest that the area of maximum vorticity advection "leads" the sea level low center. In fact, the 12-hour mean vector movement of the Low for the period t_0 to t_{0+12} appears to be in the general direction of the maximum of vorticity advection at t_0. In this particular instance, it appears to be a good clue to the unusual northwesterly motion of the storm.
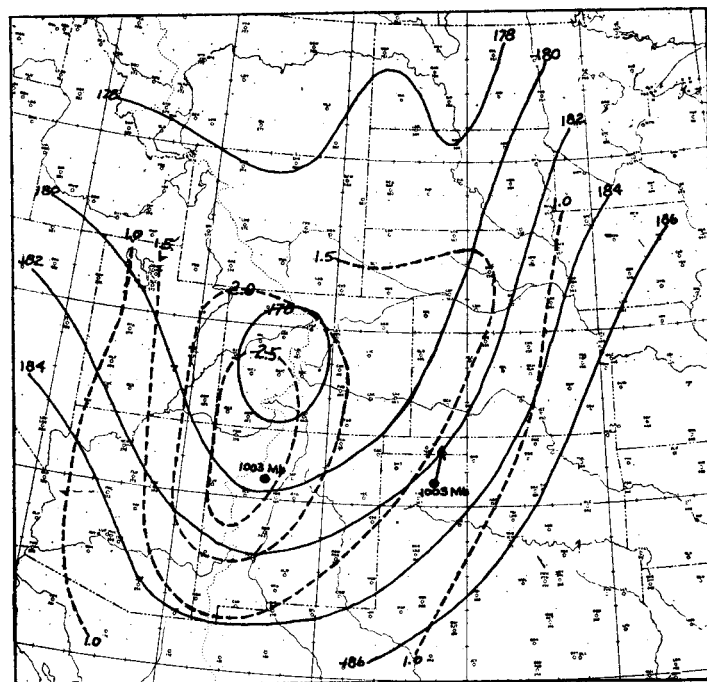
In figure 11 the development and deepening of the sea level Low are compared with the associated maximum vorticity advection. Curve A, the Laplacian of the sea level pressure (a quantity that is proportional to the

FIGURE 9.—500-mb. contours and vorticity for 1500 GMT, November 2, 1956.

FIGURE 11.—Graph showing variation with time of the Laplacian of sea level pressure (long-dashed line, A), the maximum advection of geostrophic vorticity at 500 mb. (short-dashed line, B), and central pressure (mb.) of sea level Low (solid line, C). The geographic position of the values given by curve B is not necessarily coincidental with that of the sea level Low.

FIGURE 10.—500-mb. contours and vorticity for 0300 GMT, November 3, 1956.

FIGURE 12.—Chart at 500 mb. for 1500 GMT, October 31, 1956, showing winds, selected temperatures (° C.), and temperature changes (° C.) for the preceding 12-hour period (numbers encircled).
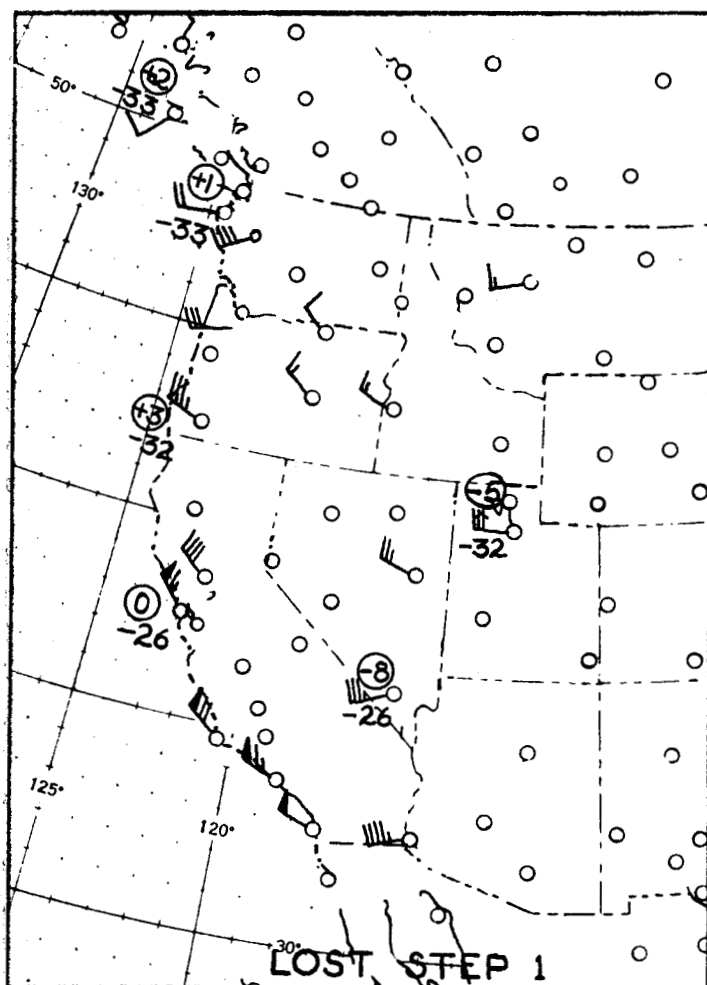
FIGURE 13.—Wind, temperature, and 12-hour temperature change chart for 0300 GMT, November 1, 1956.
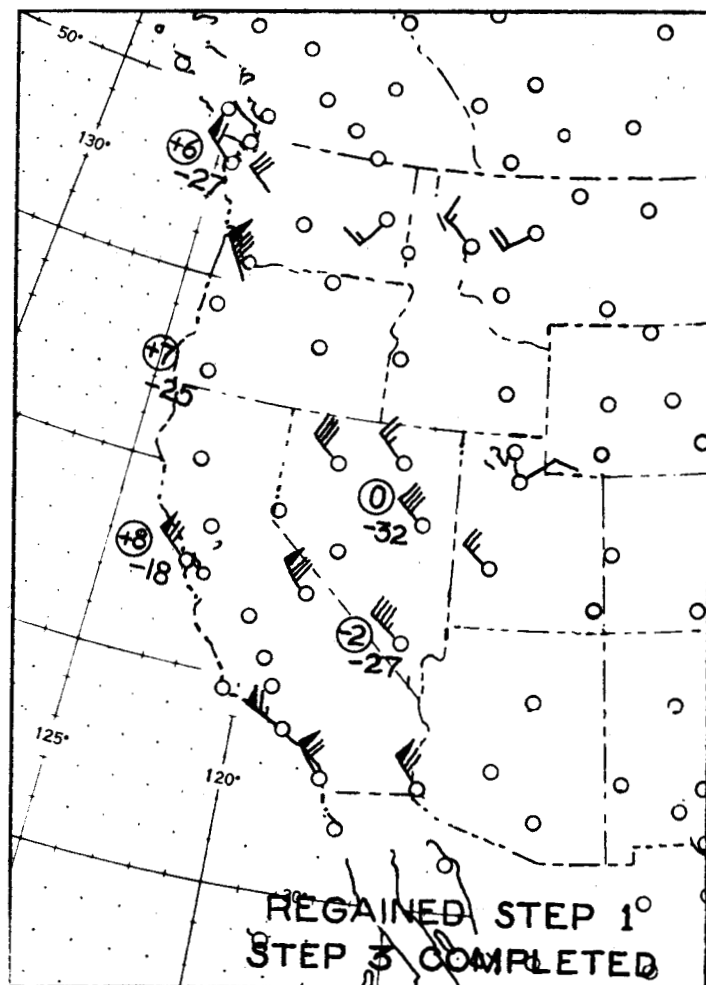

FIGURE 14.—Wind, temperature, and 12-hour temperature change chart for 1500 GMT, November 1, 1956.

sea level geostrophic relative vorticity), was computed by the formula

$$\nabla^2 p = \frac{p_1 + p_2 + p_3 + p_4 - 4p_0}{D^2}$$

where p_0=central pressure of the sea level Low.

p_1, p_2, p_3, p_4=sea level pressure at points 4° latitude distance at each of four cardinal directions from the low center.

D=4° latitude.

Vorticity advection, curve B in figure 11, was taken as the maximum value of positive advection at the 500-mb. surface computed from the geostrophic wind field.

The intensification of vorticity advection appears to have occurred roughly simultaneously with the development at sea level (fig. 11), although precise timing of vorticity advection intensification is difficult since the interval between maps is 12 hours. Thus, from the diag-

nostic standpoint, development appears to have occurred in accordance with Petterssen's hypothesis. However, from the standpoint of forecasting development within this framework, it would have been necessary to forecast the intensification of the vorticity advection pattern that actually occurred mainly between 01/1500 GMT and 02/1500 GMT. That this could have been done is somewhat doubtful.

For other reasons, to be discussed later, the possibility of important development was mentioned by the forecast staff at the Weather Bureau District Forecast Center, Kansas City, as early as the forenoon of October 31. An alert to the possibility of development of severe weather over the High Plains for the night of November 1–2 was included in the FP–1 discussion of 01/0339 GMT. Formal warnings for heavy snow and strong winds were issued at 02/0339 GMT, and increased to blizzard warnings at 02/0939 GMT.

4. THE FORECASTING OF DEVELOPMENT

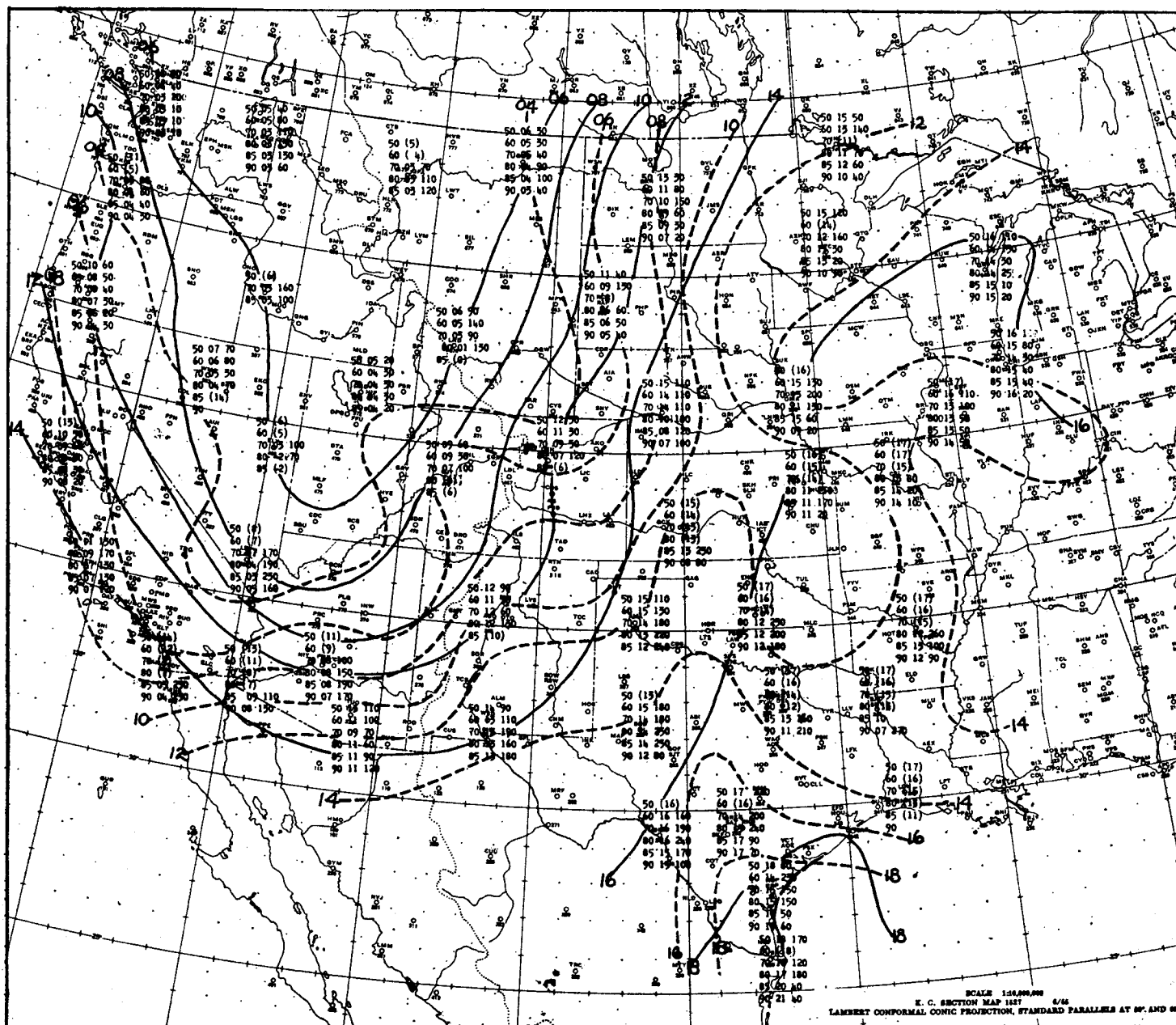The "Colorado" type development is considered one

FIGURE 15.—Theta prime chart for 1500 GMT, November 1, 1956.   First column of plotted figures is the pressure level indicator; i. e., 90 for 900 mb., 85 for 850 mb., etc.   Second column is wet-bulb potential temperature in ° C.   Third column (where shown) is the lift in millibars required to reach saturation.   Also shown are isotherms of θ' at 500 mb. (solid lines), and at 850 mb. (dashed lines).

of the most acute forecast problems of the Great Plains region.   To meet this challenge, the Kansas City Forecast Center has, for the past several years, utilized a system involving several antecedent steps that comprise direct clues to area of development, time, and intensity. The steps must by necessity be reduced to their simplest form with the absolute minimum of exceptions and must apply to the 500-mb. level.

Step 1: A shift in wind flow to a northerly component at Seattle and/or Tatoosh at the 500-mb. level. It is important to note that this northerly component

must be retained through the entire period of development.   It may also be noted here that losing the criterion of Step 1 may involve the approach of another wave or foreshadow the formation of a cutoff cold vortex over the Plateau.

Step 2: A fall in 500-mb. temperature at Medford, reaching a value of −25° C. or lower.

This is an essential step (although in many cases it may appear to occur simultaneously with Step 1) and is necessary as an indicator of intensification of the approaching or developing trough in that region.
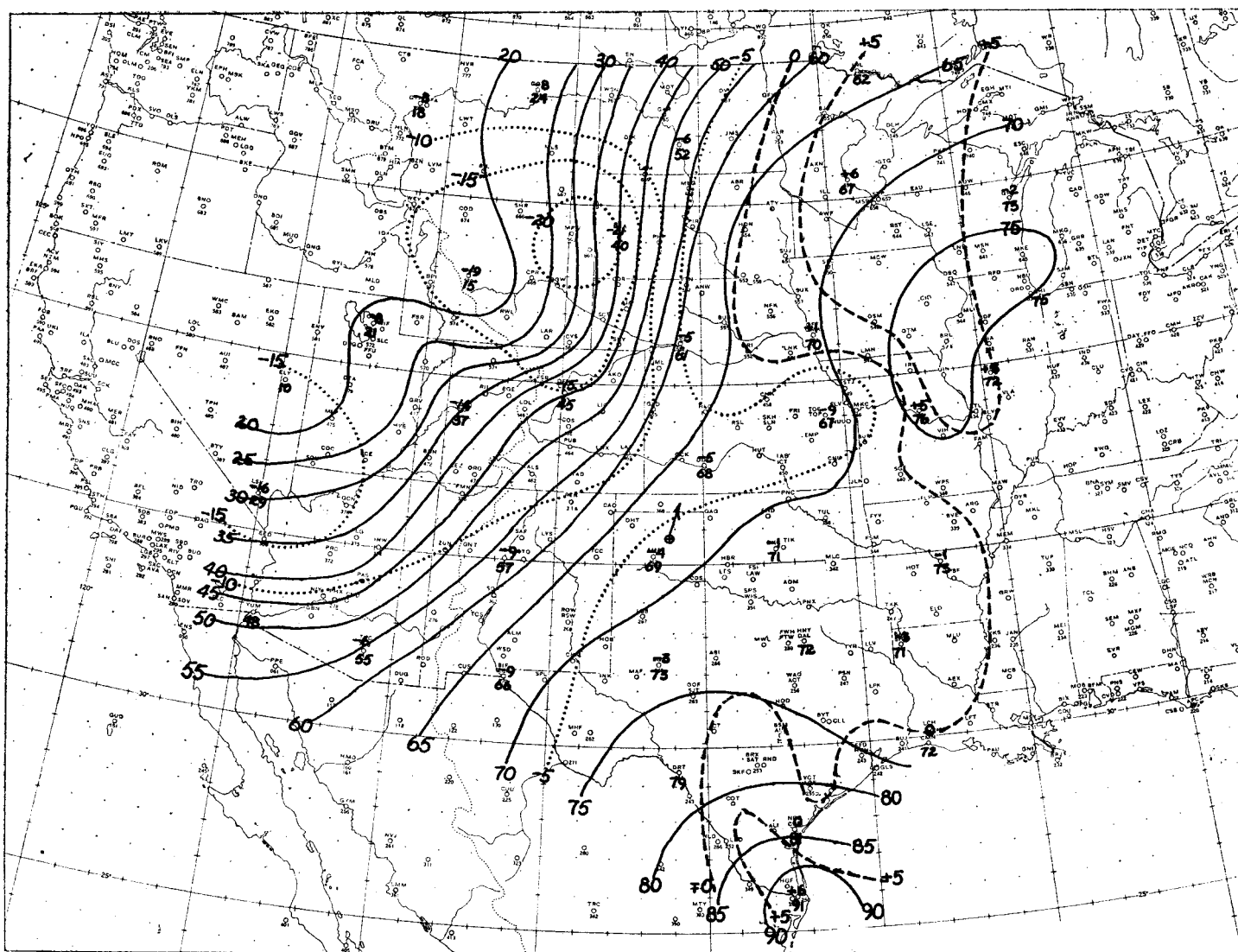
FIGURE 16.—Chart for 1500 GMT, November 1, 1956, showing isopleths of the summation of θ' from 850 mb. upward through 500 mb. (solid lines), and changes in these values during the preceding 12-hour period (dashed and dotted lines). Location of sea level Low indicated by $\oplus$, future 12-hour movement shown by arrow.

Step 3: A fall in temperature to a value of $-25°$ C. or lower at Ely and/or Las Vegas attended or shortly followed by a distinct temperature rise at Medford.

This will then assure necessary amplitude and southward extension, and sufficient eastward motion of the trough to effect and promote a distinctly favorable area of cyclogenesis in the region of southeastern Colorado. It is again emphasized that Step 1 must be held through Step 3 to preserve the sequence of necessary developments.

This forecast procedure was utilized and is well illustrated in the November 1–3 case of development. In light of the above discussion of the three steps, consideration of conditions preceding the development of November 1–3 shows that Step 1 was first apparent on the 500-mb. chart at 1500 GMT, October 31 (fig. 12), making possible issuance of our first alerts at that time.

Step 2 was almost simultaneous and was already assured due to prevailing conditions at the time.

Step 1 was lost by 0300 GMT November 1 (fig. 13) due to the approach of another short wave, thus delaying development 12 to 18 hours. However, it will be noted that Step 3 became a very distinct feature by 1500 GMT, November 1 (fig. 14), making possible the issuance of bulletins and warnings during the late afternoon and evening of that day.

5. FILLING STAGE

The trough at 500 mb. closed off in its southern portion before development occurred, but retained enough asymmetry to maintain a significant vorticity advection pattern. As has already been shown (fig. 10), by 03/0300 GMT the vorticity advection area had shifted to the north-
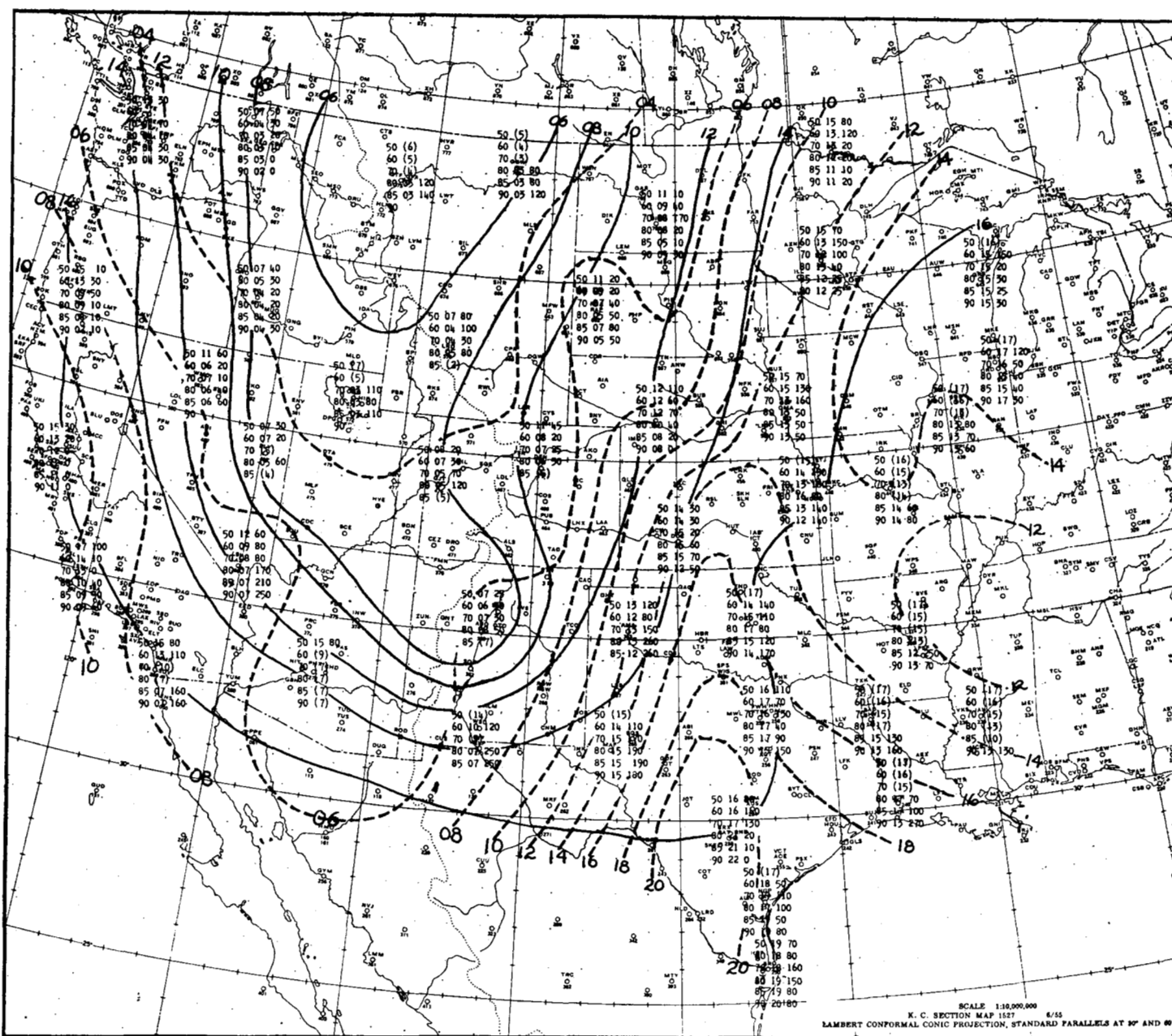
FIGURE 17.—Theta prime chart for 0300 GMT, November 2, 1956.

west quadrant of the 500-mb. Low. Subsequently, the upper Low drifted in a northwesterly direction. At the same time it became somewhat more circular and consequently the strength of the vorticity advection pattern diminished. As this occurred the surface Low moved northwestward and filled rapidly.

6. APPLICATION OF THE THREE-DIMENSIONAL POTENTIAL WET-BULB TEMPERATURE (θ')

DESCRIPTION OF θ' CHART

The theta prime chart consists of a plot of potential pseudo-wet-bulb temperatures (θ') in the vertical at

standard levels 900, 850, 800, 700, 600, and 500 mb. In addition, the amount of lift in millibars required for saturation is plotted for each level. Where humidity values are "motorboating," the value of θ' is placed in parenthesis with the dew point taken as the maximum "motorboat" value for the observed temperature.

The chief value of a chart of this kind is that it facilitates a grasp of temperature-humidity relations and stability in a three-dimensional field.

DEVELOPMENT

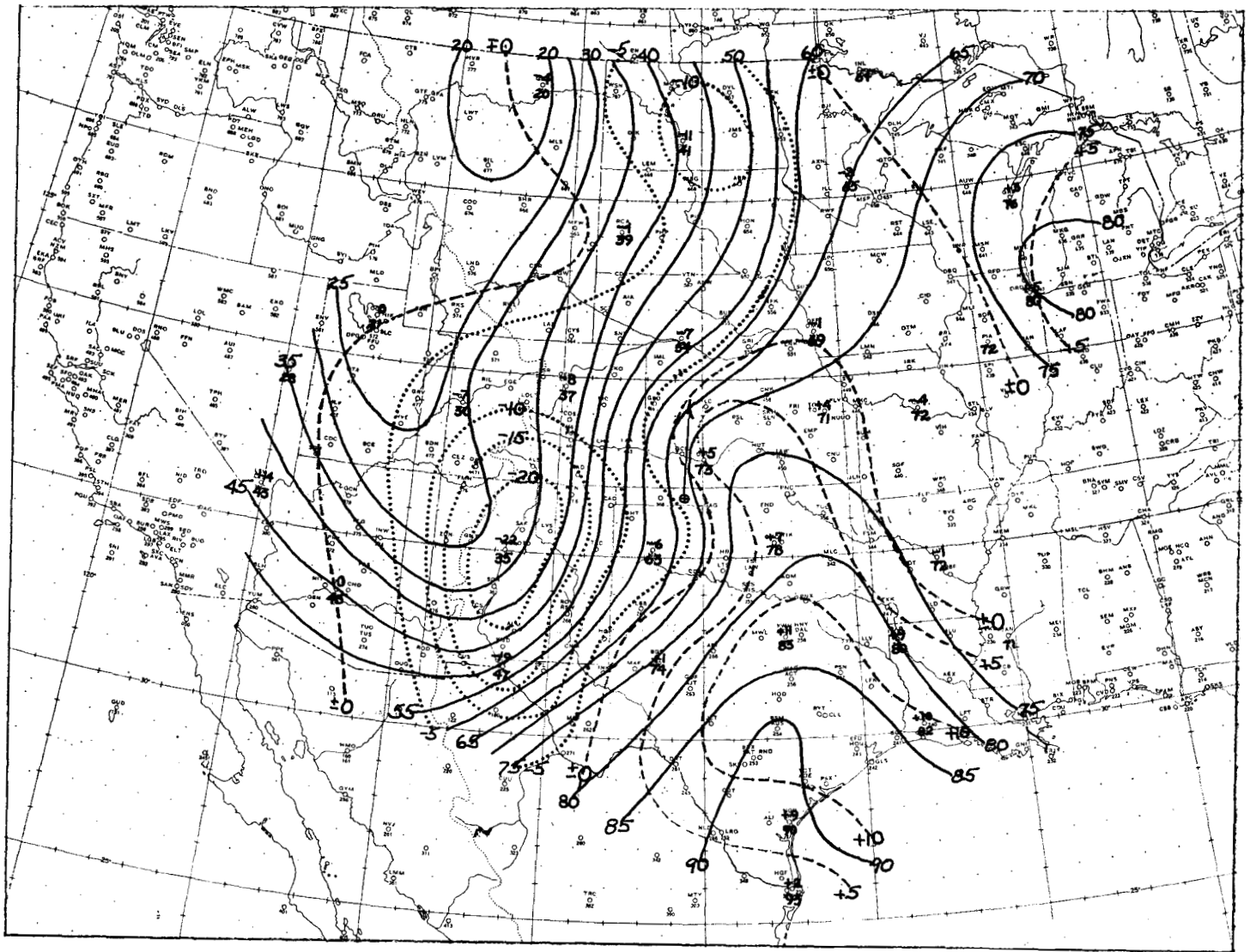Petterssen's [2] development equation may be written in the form

FIGURE 18.—Summation of θ' and its 12-hour change, 0300 GMT, November 2, 1956.

$$(1) \qquad \frac{d\eta_0}{dt} = -\mathbf{V} \cdot \nabla \eta - \frac{\partial \zeta_s}{\partial t}$$

where subscript 0 refers to a low-level surface of pressure p_0 and subscript s refers to shear through the layer from p_0 to the level of nondivergence at pressure p. Thus the first term on the right side of equation (1) is the advection of vorticity at the level of nondivergence; this term was evaluated at the 500-mb. level in the foregoing discussion. The second term can be shown by use of the thermal wind equation to be essentially

$$(2) \qquad -\frac{\partial \zeta_s}{\partial t} \simeq -\frac{R}{f} \ln \frac{p_0}{p} \nabla^2 \frac{\partial \overline{T}}{\partial t}$$

where R is the gas constant, f the Coriolis parameter, and $\overline{T}$ is the mean virtual temperature of the layer between p_0 and p. Because our primary interest is in the mean temperature field after the layer becomes saturated

(in which case $\overline{T}$ is proportional to $\bar{\theta}'$), it is proposed to change (2) to the following:

$$(3) \qquad -\frac{\partial \zeta_s}{\partial t} \simeq -\frac{kR}{f} \ln \frac{850}{500} \nabla^2 \frac{\partial \bar{\theta}'}{\partial t}$$

where k is the constant of proportionality between $\overline{T}$ and $\bar{\theta}'$ for the saturated layer. For qualitative use, $\Sigma\theta'$ can be substituted for $\bar{\theta}'$, and $\partial\bar{\theta}'/\partial t$ expressed as the change per 12 hours, $\Delta\Sigma\theta'/12$. This principal variable, $\Delta\Sigma\theta'/12$, is evaluated in the following manner. Sum the θ' values for each sounding from 850 mb. through 500 mb. and place on an auxiliary chart. Twelve-hour changes ($\Delta\Sigma\theta'/12$) are made from these values and the change field is analyzed. Although according to equation (3) it is the Laplacian of this change field that is important, attention here is restricted to an inspection of the centers of change, centers of warm and cold advection, and the gradients about these centers.
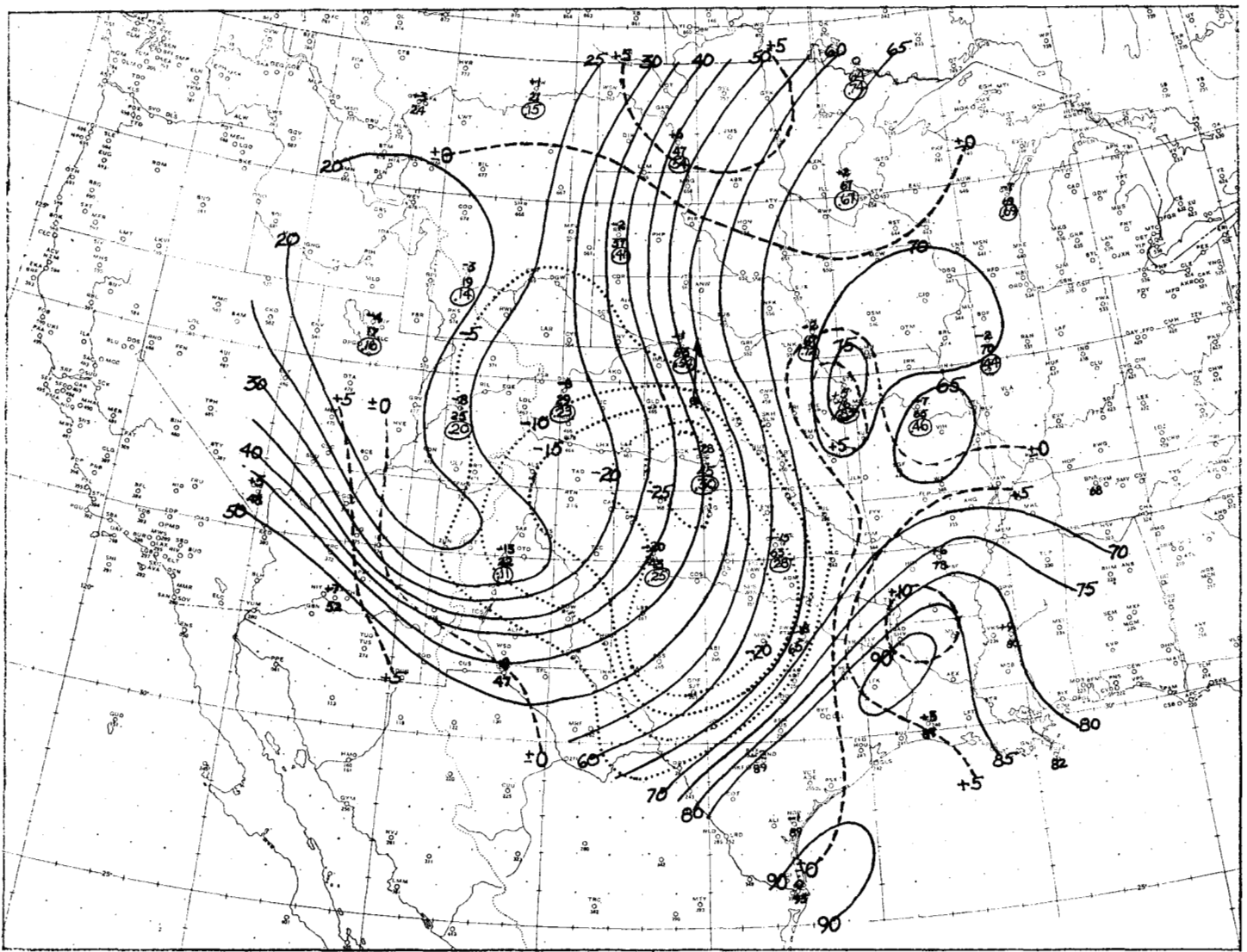
FIGURE 19.—Theta prime chart for 1500 GMT, November 2, 1956.

The first wave to move around the cold trough moved north-northeastward through the Dakotas, filled, and was centered in North Dakota on the 1230 GMT November 1 surface chart (fig. 5). This wave had the effect of shifting low-level winds to northerly in the High Plains and dropping temperatures into the range where later precipitation would be snow. This is shown as maximum of cooling over Wyoming and western South Dakota with warm advection over Iowa and Minnesota in figures 15 and 16. The same charts show that another maximum of cooling was approaching in Arizona with the beginning of a warm tongue from western Texas north to Dodge City.

By 0300 GMT, November 2 (figs. 17 and 18) the cold advection, centered over Albuquerque, was quite strong and warm advection had developed further, extending from southern Texas northward into south-central Kansas. The easterly component of the thermal wind was increasing north of the cold advection center and for the following 24 hours the actual low-level winds turned to easterly north of the low center.

Twelve hours later (figs. 19 and 20) cold advection had reached the Plains of Kansas and had begun to cut off the southerly winds east of the low center. However, moisture values were high in Minnesota and Iowa, partly residual from the first wave of the series. This moisture was beginning to move westward and precipitation continued north and west of the low center.

FIGURE 20.—Summation of θ' and its 12-hour change, 1500 GMT, November 2, 1956. Encircled figures are computed precipitable water.

PRECIPITATION AMOUNTS

Hewsen [3] has shown a method of forecasting precipitation amounts and has given a statistical relation between a decrease in θ' with height and the amount of precipitation in a following 12-hour period. Some modification of Hewson's idea can be used here.

An examination of the soundings for 1500 GMT, November 2 (fig. 19), at the time cold advection had covered Kansas, shows upslope conditions existed from east to west at all levels from Minnesota and Iowa westward to the mountains. The maximum in this slope as shown by the strong horizontal gradients of $\Sigma \theta'$ in figure 20 extended from central North Dakota southward into western Nebraska. While the low-level winds were easterly, winds at 500 mb. were advecting cold air from the south causing convective instability along the east side of the $\Sigma \theta'$ gradient. North Platte had a condition of neutral

instability for the saturated state at the 800-mb. level and above.

The amount of precipitable water was computed for 1500 GMT, November 2, by the method of Solot [4] and entered as the third number in the station model of figure 20. There existed a moisture differential of some 0.55 inch between the air mass in Iowa and Minnesota and the two soundings in Colorado. It is our experience that in a developing storm the soundings in the cold air take on a saturated lapse rate through the 500-mb. wet-bulb temperature. As represented by the Denver and Grand Junction soundings, absorption of some 0.20 inch of water was indicated, while the soundings to the east in the source region showed an average of about 0.75 inch available. This excess could be realized as precipitation along the maximum gradient of slope and in a time interval determined by the winds.
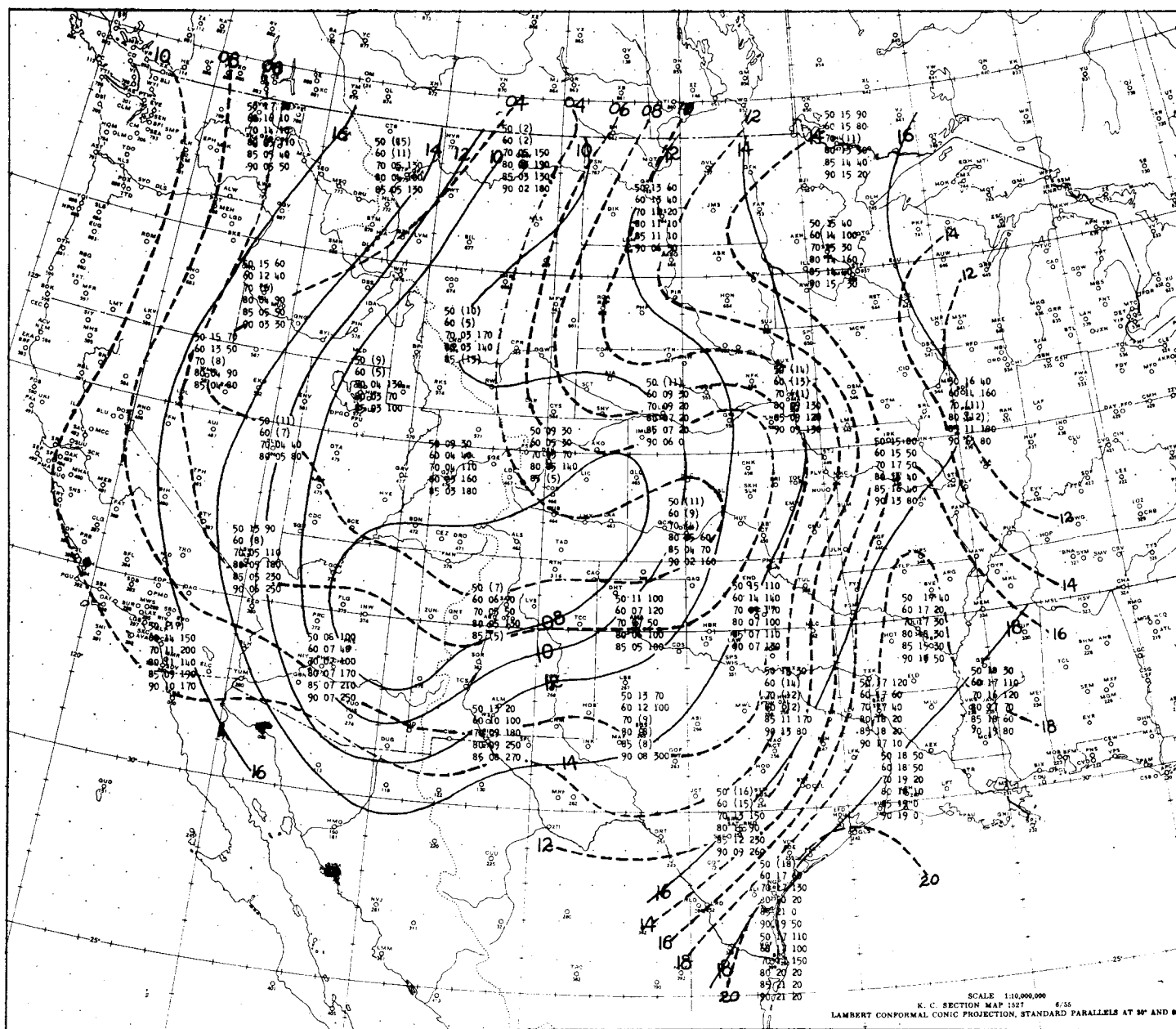
FIGURE 21.—Theta prime chart for 0300 GMT, November 3, 1956.

There were few observations of the wind north of the low center, but with 25 kt. taken as a mean value of the easterly component for the soundings from the surface to 500 mb., 0.55 to 1.10 inches of precipitation would be expected in the 12-hour period following the 1500 GMT, November 2, soundings. This precipitation would be confined principally to the zone of convective instability and the maximum slope. The 24-hour amounts of precipitation ending 1230 GMT, November 3, are shown in figure 23.

Figures 21 and 22 show the continuing occluding process with the thermal advection centers, suggesting the more northwest direction for the surface Low.

Such a detailed analysis is hardly feasible on a routine basis at present in the District Forecast Center. However, soundings between the Mississippi River and the Rocky Mountains are usually plotted and processed on a θ' chart to give a measure of slope, the available moisture, and in a qualitative way the changes in warm and cold advection centers that would exist should saturation occur.

7. CONCLUSIONS

(1) From the diagnostic standpoint, the development of this storm appears qualitatively to have occurred in accordance with Petterssen's development hypothesis; but
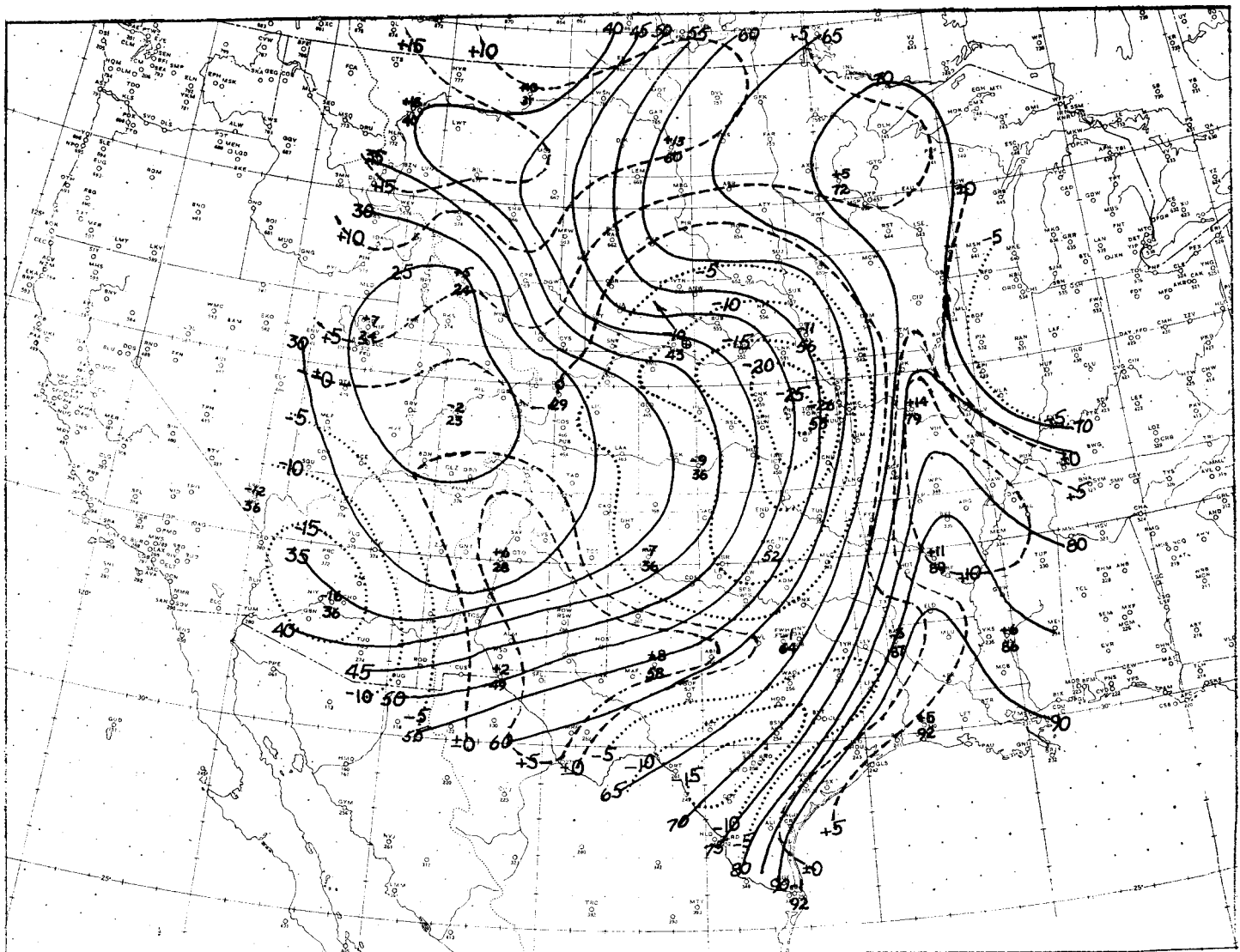
FIGURE 22.—Summation of θ' and its 12-hour change, 0300 GMT, November 3, 1956.

the degree of development, which is related instantaneously in Petterssen's development equation to the degree of vorticity advection, likely would not have been forecast from these considerations alone because of the necessity to forecast independently the movement and development of the upper trough.

(2) This case contains the suggestion that the sea level Low tended to follow the area of maximum vorticity advection at 500 mb. Although this result is not entirely unexpected, the relation should be investigated further to determine circumstances under which it may or may not hold.

(3) A useful tool in forecasting development in this case

(as in many others) was the progression through the three "steps" at the 500-mb. level.

(4) A useful tool in forecasting precipitation is the vertical theta prime chart. At or near saturation, it suggests the slope of isentropic surfaces. It also suggests the degree of vertical stability and changes therein.
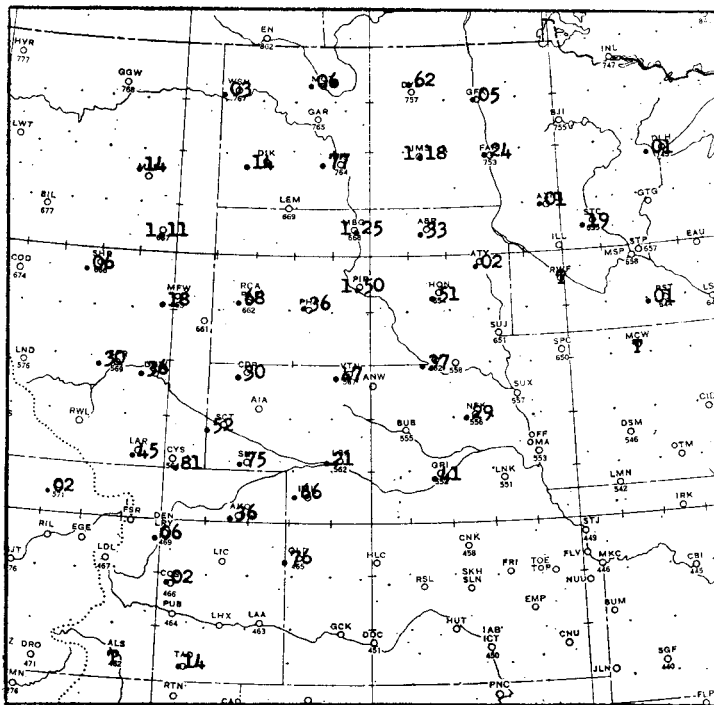
ACKNOWLEDGMENTS

FIGURE 23.—Chart showing reported precipitation amounts for the 24-hour period ending at 1230 GMT, November 3, 1956.

REFERENCES

1. Sverre Petterssen, Gordon E. Dunn, and L. L. Means, "Report of an Experiment in Forecasting of Cyclonic Development," *Journal of Meteorology*, vol. 12, No. 1, February 1955, pp. 58–67.

2. Sverre Petterssen, "A General Survey of Factors Influencing Development at Sea Level," *Journal of Meteorology*, vol. 12, No. 1, February 1955, pp. 36–42.

3. E. W. Hewson, "The Application of Wet Bulb Potential Temperature to Air Mass Analysis. III. Rainfall in Depressions," *Quarterly Journal of the Royal Meteorological Society*, vol. 63, No. 271, July 1937, pp. 323–331.

4. Samuel B. Solot, "Computation of Depth of Precipitable Water in a Column of Air," *Monthly Weather Review*, vol. 67, No. 4, April 1939, pp. 100–103.